Renewable energy for smallholder irrigation

A desk study on the current state and future potential of using renewable energy sources for irrigation by smallholder farmers.

May **2014**

SNV

SNV at a glance

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Starting out in the Netherlands nearly 50 years ago, we now work in 38 countries in Africa, Asia, and Latin America. Our global team of advisors use their specialist expertise in Agriculture, Renewable Energy and Water, Sanitation & Hygiene to contribute to solving some of the leading problems facing the world today.

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Our objectives in Renewable Energy are:

- To realise access to sustainable, clean and reliable energy sources for households and businesses including small producers, while reducing greenhouse gas emissions.
- To foster an enabling environment whereby local existing organisations are strengthened or established, and sound policies, including regulation, quality assurance and governance, are developed.

This translates into Renewable Energy activities in 25 countries across Asia, Africa, and Latin America, where we provide technical assistance and capacity building.

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Executive summary

This study summarizes experiences using Renewable Energy (RE) water pumping options as irrigation by smallholder farmers in developing countries. It includes an overview of conventional technologies (petrol and diesel pumpsets),along with an inventory of RE alternatives (windpumps, solar Photo Voltaic[PV] pumps, solar thermal pumps and biogas). Other technologies included in this study are hydram pumps, biomass, bio-fuel and hybrid systems, which all have limited potential for smallholder irrigation.

Based on a simple calculation model, a comparison was made of potentially viable RE options under specific conditions and for specific smallholder characteristics, which can be adapted to the local context. It can be concluded from the comparison of these technologies that the **break-even point for RE, in reference to fossil fuels**, can only be reached with intensive use of irrigation equipment. Small pumpsets are still the low-risk option and financially more attractive when used occasionally. This relates also to the **cost of ownership and cost of use** (low - high for fossil fuels and high - low for RE options). With the limited purchasing power of smallholders, coupled with the relatively high investment costs of RE options, loans are required. Financing costs can be a major part of annual costs, especially when loans are taken at the usual high interest rates.

A visible market trend shows that prices of PV irrigation pumpsets are becoming available at affordable prices, which are continuing to drop. This, in combination with rising fuel prices, point towards favourable conditions for a major change in smallholder irrigation practice. However, knowledge of the best alternatives is not readily available and unfavourable financing conditions will be a substantial bottleneck.

Based on these findings, external support from international organizations would be useful in encouraging smallholder farmers to use RE for irrigation as replacements for fossil fuel appliances in order to improve energy efficiency and reduce emissions. Such external support is needed primarily in the areas of 1) technology, 2) marketing and 3) financing. A private sector approach appears to be the way forward in this, where international organizations could boost the market through promotion of the most viable RE options on the one hand, while simultaneously helping the private sector establish supply chains for successful market introduction. These supply chains would need to be able to import the best products, facilitate distribution, and provide dealer and service networks for a fully functioning market. The local financing sector needs to be engaged in order to offer loans specifically suited for smallholder farmers' investments in RE irrigation equipment.

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List of abbreviations used

RE	Renewable Energy
SHI	Smallholder irrigation
Hp	Horsepower; 1hp = 735Watt
MFI	Micro Finance Institution
PV	Photo Voltaic

1. Introduction

This study presents the results and findings of the desk study on RE for irrigation, and gives recommendations to boost the development of renewable SHI (Smallholder irrigation) technologies. It was carried out in 2013 by the PRACTICA Foundation for SNV.

The study consists mainly of an inventory and analysis of experiences in RE for irrigation in developing countries worldwide that have been successful in improving the living conditions of their low-income populations.

In addition, the study makes a set of recommendations for the application of RE in irrigation, by focusing on fossil fuel/appliance replacement.

This study regards the smallholder farmer as a commercial producer. Current RE irrigation options are compared and evaluated in the context of existing technologies-mainly diesel and petrol-powered pumpsets. Economic benefits in a non-subsidized market form the basis for a positive evaluation of RE options.

This desk study describes the most appropriate technologies of RE for smallholder irrigation in terms of technical, social and financial viability. Attention is given to the opportunities as well as the risks and constraints of adopting RE for SHI.

The collection of data for this desk study was carried out in several ways: copious amounts of information were collected during semi-structured (phone) interviews with key persons from local and international companies, NGOs and institutions. Furthermore, relevant literature was consulted. See Annex 2 relevant background documents consulted and Annex 3 contributors.

2. Results and Findings

2.1 Renewable Energy

Developments in the energy sector with respect to innovations and the use of sustainable sources are fast and large. RE covers about 20% of global energy use today[1]. Approximately 30% of investments in RE are in wind energy and 60% in solar energy. Major investors are USA, Japan, Germany, China and India.

On national scales, currently decentralized, RE is being integrated into the national grids and into micro-grids and off-grid solutions as well. National grids are expected to expand by 40% worldwide over the next 20 years, of which around 40% shall come from RE. Likewise, the micro-grids and off-grids solutions will grow by 40% and 20% respectively, of which 90% is expected to come from RE[2].

1 GEA, Global Energy Assessment - Toward a Sustainable Future, 2013.
2 Simonet, E., Alternative Energy Grids, February 15, 2013.

Although irrigation using grid-based solutions seems to be a logical option, the grids in developing countries, when existing[3], are often not equipped to handle the extra load or are simply not reliable enough to be used for irrigation due to frequent power cuts and voltage variations, making off-grid solutions (both conventional and RE options) still an important alternative. In Pakistan for instance the cost of bringing electricity by extending the grid to the farm has become prohibitively expensive as the cost has to be borne in full by the farmers.

2.2 Inventory of RE Technologies and their success

Currently, the common sources of power for smallholder irrigation are either petrol or diesel fuel. In cases where an electric power grid is available, electric power is also being used. Although there are many types of alternative and RE sources, only a limited number of sources are directly applicable to small-scale irrigation (depending on price, efficiency and current state of development). While solar energy is the most obvious, wind and water offer fewer options. Others types of RE are of minor importance for irrigation.

To come to a full overview of potential energy sources for smallholder irrigation, in this section all energy options are discussed (both renewable and conventional), along with the advantages, disadvantages and limitations in application:

Petrol pumpsets (conventional energy option)

Small petrol engine-driven pumps in the range of 1.5-4hp are at present the preferred option for SHI. These pumpsets are relatively cheap to buy, available in most regional capitals and maintenance can be assured by rural mechanics. The small size and weight enables farmers to take the pumpsets home, avoiding the risk of theft.

As a disadvantage, the pumpsets generally do not last long, and fuel and maintenance costs are high.

In many instances, the capacity of the pumps exceeds the requirement for SHI and unless the farmer has access to surface water, the wells cannot cope with the full capacity of the pumps. For this reason, the pumps are operated at a low efficiency, resulting in relatively high fuel consumption for the amount of water pumped. Generally, the lower power rated pumps perform better for SHI but as price ranges are similar to much bigger pumps, farmers tend to prefer the higher power-rated (hp) pumpsets not realizing that these are less efficient[4].

Small engine pumpsets are always equipped with centrifugal pumps, which can draw water from a maximum depth of 7 meters. If the water is deeper, pumps are sometimes installed closer to the water table by digging a large pit. In this way the range of the pump can be extended to about 11 meters.

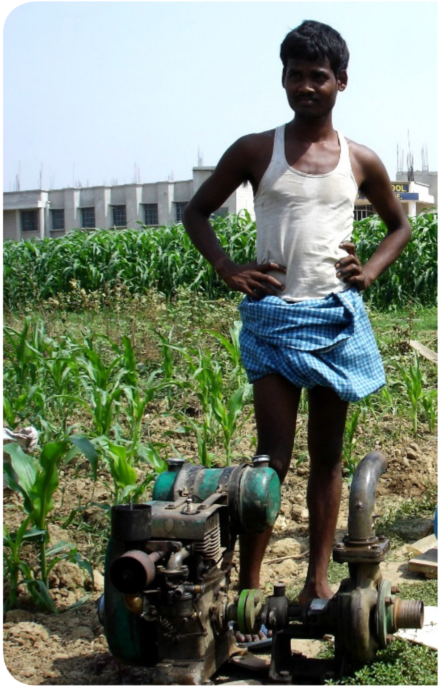

Figure 1
Small petrol irrigation pumpset

[3] Grid is only available to 0.8% of the rural population in Niger.
[4] Rapport Banc d'essais motopompes, Stephan Abric, August 2000.

The average lifetime of these pumps has been estimated at four years. In hot and dusty environments this may be reduced to a maximum of two years, but in cooler and cleaner environments it may go up to six years.

The farmers do not generally stock larger quantities of fuel (due to risk of fire and theft) and thus need to go frequently to the nearest town to buy fuel. This is an unwelcome chore. Moreover, the use of fuel not only contributes to CO_2 emission and air pollution, but also to spillage that pollutes the soil and likely the groundwater as well.

Diesel pumpsets (conventional energy option)

Diesel engine driven pumps start from power ratings of 4-5hp. The pumpsets are more expensive than petrol pumps, heavier, more difficult to operate and repair, and generally have a capacity that exceeds the water needs and well yields for SHI. For larger farm sizes, diesel pumps are interesting because diesel fuel is usually cheaper than petrol fuel, the overall fuel efficiency is higher, and longevity is better than petrol pumpsets. As these pumps are generally heavy, they are either left in the field (sometimes with a watchman) or transported home by cart.

Figure 2 Indian diesel irrigation pumpset

The higher fuel efficiency and longer lifetime are offset by the higher maintenance costs and the initial investment, especially in situations where the diesel pumpsets are used at partial capacity or seasonally[5]. In Pakistan the locally manufactured diesel engines or Petter engines are used to draw water. These are very sturdy engines, easy to operate and maintain, and the cost of replacing parts is reasonable as they are locally manufactured. The benefit of these versatile engines is that they can be used for multiple tasks such as for tilling land, operating fodder choppers including drawing water for irrigation.

Solar Photo Voltaic (PV)

Solar Photo Voltaic is the generic name referring to the conversion of solar energy directly to electric power. Medium and large scale solar PV panels are used widely in places without grid connectivity to power applications like communication systems. They are increasingly used as well for power generation connected to the grid. Micro PV is extensively used to charge battery-powered devices like domestic lighting. The share in RE is growing annually. The main reason is that the price of solar panels is still falling, while at the same time the performance increases[6]. This is partly the result of mass production, competition and large investments in improved technology. The technique has been proven[7] and thus solar panels are now produced by many producers around the world. They can be placed wherever there is enough sun, and because of their modular nature, solar panels can be applied at any scale. Furthermore, installation is relatively simple and the technique is identical for large and small systems.

[5] One of the reasons that diesel pumps used for irrigation have relatively high maintenance costs is that, since they are used seasonally, condensed water is formed in the fuel which corrodes the fuel injection system components, thus requiring annual replacement of these parts.
[6] Prices of solar panels have dropped 30 - 60 % over the last decade, and are still getting cheaper annually by 10 - 15%. Moreover, the PV cell efficiency increases by 0.5% a year (OECD/IEA).
[7] This is true for domestic as well as for industrial use, under moderate and extreme weather conditions.

Although systems for water pumping applications for smallholder farmers are considered to be small size, investments are significantly higher than comparable petrol and diesel pumpsets. Their use is limited to some 8 hours per day as energy storage is financially not viable for crop production. Water pumping systems consist of a solar panel, a controller unit, and a motor-pump unit.

For this research, a distinction was made between high-end systems from European manufacturers for example, and low-end systems entering the market mainly from Chinese producers.

Figure 3
Solar pumping system for irrigation;
Solartech product brochure

Low-end solar pumps powered by PV panels come in a variety of models, prices and capacities but to date there is no recorded field data regarding the actual performance and lifetime of the complete system or its components. A comparative test has been conducted in Tanzania where a number of Chinese PV pumps were evaluated on performance and cost.[8]

The lack of field data makes it difficult to estimate the lifetime and thus the annual cost of these systems. The assumptions made in the technology comparison calculations are informed guesses, but include a large margin of error.

The obvious advantages of PV pumping systems are that they cause no pollution, require no frequent trips to the nearest town for fuel, and are very easy to operate. On the downside, they are not flexible in terms of output per day. They are limited to a maximum of 8 hours per day of pumping while the sun shines, or less under cloud cover.

As the crop water requirement varies over the growing stage of the plants, a solar pump has to be sized for the maximum water requirement, which may be needed only 30-40% during the total season. A petrol or diesel engine pump can simply be run more hours per day to cater for extra water need.

Solar pumps, and especially the PV panels, cannot be left in the field for risk of theft[9] and thus need to be taken home. As the panels are often 1m^2 or more, plus the pump, this is not always easy. As for diesel engines, this may require a cart.

Unlike combustion engines which can usually be repaired by replacing a part, solar PV pumps, when out of order, will need the replacement of an entire component such as a panel, controller or motor/pump unit. Rural mechanics will have to be trained to identify which component is faulty and these components are expensive. In other words, whereas a farmer with a petrol pump faces regular small expenses to keep his pump running, a farmer with a solar PV pump will face irregular but high expenditures, which are generally harder for farmers to cope with.

[8] MSABI-Development of solar driven irrigation (Tanzania, 2013).
[9] As the PV panels are expensive, durable and versatile (can be used for applications like battery charging for light or television), the market value for second hand panels is high. This makes the panels very much prone to theft and applications with stand-alone systems in African countries usually need to be guarded during the night.

For the sake of comprehensiveness, European brand solar PV pumps have been included in the comparison, but it is obvious that these pumps are too expensive to be considered for SHI. They can only be considered for larger systems where the higher reliability and longer lifetime make them economically viable, or, for community drinking water systems.

Solar Thermal

Another option of using solar energy for pumping is using solar thermal energy. In most systems, the solar energy is used to heat a medium (liquid or gas), which transfers the thermal energy to an engine (can be either a turbine, steam engine or Stirling engine). In the engine, the thermal energy is converted into mechanical power that can be used to drive a water pump. Alternatives that are under development include a liquid piston pump.

Although steam engines, turbines and Stirling engines all have (had) their industrial application, there are no records of commercial successes of these technologies in combination with a solar heat collector. This is surprising, as although the systems are mechanically more complex than PV systems, there is a potential to make solar mechanical power available at lower costs than the current PV system costs.

Figure 4 Solar thermal pump Sunflower

PRACTICA has worked on the development of a thermal solar pump. The design of this pump has been transferred to a company[10], which is now producing the pump in India and marketing it under the brand name Sunflower pump.

The design of the Sunflower pump is built around principles of appropriate technology - in other words it is low cost, simple to operate, and easy to maintain and repair locally. This pump uses the heat of the sun to operate a small steam engine, which in turn drives the water pump. The configuration of this pump allows manual pumping. In this way the pump can also be used for domestic water outside of sunlight hours. It also means that when the plants need more water than can be pumped using sunlight, or when no sun is available, manual pumping can provide additional water.

Although market introduction of the pump has not yet taken off fully, due to lack of alternative solar thermal pumps, it was decided to include the Sunflower pump in the comparison of RE option for SHI. Figures are based on a first series of ten pumps that have been field tested in Ethiopia since 2011[11]. Market introduction of the pump will start in 2014 and will focus on Kenya and Ethiopia.

[10] www.futurepump.com; PRACTICA has no commercial interest in this company, nor in the Sunflower pump product.
[11] http://www.scribd.com/doc/57081613/SolarSteamPump-Ethiopia, Mcs thesis Nick Jeffries.

Wind Power

In remote areas around the globe, windmills have been the common technology to fill watering places for livestock in combination with a tank for a few days of buffer. However, reliability on the wind is a major challenge and in several countries, such as the USA, Australia and Namibia, traditional windmills are progressively being replaced by solar pumps, mainly because of smaller (re)investment costs, lower maintenance costs and higher reliability.

Only in very few countries, the wind regime is reliable enough as a source of energy for irrigated agriculture, even when combined with storage; a few windless days could be fatal for the crop. The limited applicability of wind power for smallholder irrigation has been backed up by this desk study, where only few technologies were found. It appears that the only wind pump used for SHI is the wind rope pump and only in Nicaragua and Cambodia. Altogether there are several hundreds of these pumps installed. The classic windpumps that are widely used in North America, South America, Australia and South Africa are no longer on the market and cost €1500-4000,[12] they are therefore too expensive to be considered. Another model that is mentioned for irrigation is the Poldaw windmill. The smallest version is the 1.8m diameter version with a capacity of 8m3 /day at 7m water depth and 3m/s wind speed. This model fits well with the water requirements of smallholder farmers. Pumps can be produced locally under licence. However, with a current cost indication of €1800[13], it does not qualify as a financially viable option for smallholders[14].

In Bolivia a low cost windpump is locally produced by a Baptist missionary, based on a design by Poldaw. Price indication of this pump is around €700. About 20 of these windpumps have been installed, but no reports could be traced regarding their performance. Due to their limited numbers and lack of performance data, this is not considered to be a successful model.

Although large scale successes of using windpumps for irrigations were not found, windpumps and specifically wind ropepumps are viable options in places where the wind regime is favourable; the annual cost are not higher than that of combustion engine pumps, the technology is simple and local production is possible. For this reason, the wind rope pump has been included in the calculation model. Other options like the Bolivia Poldaw model can be considered as well.

Figure 5 wind rope pump

[12] Desk study Wind Pumps (Draft), Gert jan Bom, PRACTICA Foundation, December 6th 2007.
[13] Last price indication is USD2000 in 2008.
[14] For the study we have specifically looked at options that can be managed by one single farmer. There are several options that can be considered when organising farmers in groups, but they were kept out of this report as it makes comparison of the different technologies almost impossible.

Figure 6 Hydraulic ram pump (Wikipedia.org)

Hydro Power

Micro-hydro power installations are small scale installations that generate electrical power using the flow of water. The installation consists of a water intake, a water turbine that takes the energy from the moving water and a dynamo to generate electrical energy from the rotation of the turbine. The micro-hydro systems are usually used for rural or domestic electrification, but excess could also be used to pump water to storage tanks, to use it to irrigate nearby fields. After midnight and during the daytime, less electricity is used and the surplus could be used for other purposes.

However, it is questionable as to what extent this is practical, as both electrical power and water require transportation from the household to the field and available electrical power is limited. As no examples have been found of this application for SHI, this option is not considered in the comparison.

The same holds true for **hydraulic ram pumps** or hydrams, which can "hammer" a small fraction of a larger water flow to higher elevations. Although the hydraulic ram pumps are being used for irrigation purposes, it is often easier and cheaper to build an off take in the stream and convey water along the contour, either by canal or by pipe. As the application of hydrams is very much limited to specific situations and general applicability is low, this option is not considered in the comparison.

Biogas

Biogas produced at (small) farms, is a residual product that has proven to be a very successful alternative for wood fuel as well as kerosene and LPG in many instances. On a small scale, however, it is not common to use biogas as fuel for pumps, since pumps are usually not used near biogas tanks. The engines need to be converted to run on gas (or gas with diesel), and storage of gas is required when not needed. Therefore, while it is technically feasible, the practice is not usual due to practical limitations. Large (communal) bio-digesters are presently not used for pumping water for irrigation for the same reasons.

However, when bio-methane can be produced constantly in sufficient quantities and storage and transportation issues can be solved, it can be used to power small combustion engine pumpsets. Especially for smallholder farmers, the water requirements can be covered with short running hours and fuel quantities used per day are generally low.

Recent developments

Currently, a biogas backpack is being developed, containing 1.2m^3 of biogas with a total weight of 4.4kg[15]. This volume of biogas can be transported to the field and equals the energy of 0.6 - 0.7 l petrol[16]. With the ability to run a small engine pumpset for more than one hour, it can be an alternative energy source for smallholder irrigation. This could also work in conjunction with small scale smallholder farmer biogas production, considering a standard fixed dome (4-13m^3) biogas unit for livestock manure and human excreta (> 20 kg daily) with an expected output of 1-5 m^3 biogas/day. As households use some 1 m^3 biogas daily for cooking, at least a production of 2 m^3 of biogas per day is required if both cooking and irrigation need to be combined.

Technologies to convert small petrol engines are available at an experimental scale[17] but it is expected that more research is needed to come up with a solution for easy conversion of spark ignition engines and to see the effects of the H2S that is present in the biogas on the longevity of the engine.

The use of biogas to power irrigation applications is still in the experimental phase but it has been included in the calculation tables. For cost estimation, the following figures can be considered:

- Biogas conversion kit for small petrol engines: €20-60;
- Transportation backpack (1.2m^3): €30;
- Investment in biogas unit: €500-1,200 in Africa and €200-500 in Asia for sizes that generate enough gas to run engines for several hours each day.

Figure 7 biogas backpack under development

[15] www.empowering-people-award.siemens-stiftung.org/en/shortlist/projects/biogas-backpack
[16] https://energypedia.info/wiki/Electricity_Generation_from_Biogas#Conversion_to_Electricity
[17] See for example http://northernflexienergy.kbo.co.ke/home (Kenya).

Example: Use of biogas powered pumping in Pakistan, supported by SNV

Biogas is being increasingly used by farmers in Pakistan to operate diesel engines on dual fuel mode where water pumps or so called "tube wells" are operated via an assembly of shafts and fan belts to draw water from up to a depth of 10 to 15 meters. Many farmers in Pakistan especially the Punjab Province already have tube wells which are operated using electricity or diesel engines. In the present scenario where the country is facing extreme shortage of electricity and ever rising cost of petroleum products, farmers are desperately looking for alternatives. Biogas could be such an alternative. The Pakistan Domestic Biogas Programme[18] has gathered considerable experience in the domestic biogas sector where biogas is mainly used for cooking and lighting purposes. More recently the programme has initiated construction of larger digesters for farmers who have sufficient cattle and are looking for an alternate and sustainable source of energy to power their irrigation pumps. Once the bio-digester is constructed (20 to 25 m^3) and gas generated, it was simply a matter of connecting the gas supply to the already present Petter engine. Not much modification is required when using this locally manufactured Petter engine which is known for being hardy. What little modification is required can be carried out locally. To date, 275 such plants are operating in the project area.

A typical 30 HP engine uses 3 litres of diesel per hour while drawing water from a depth of around 10 metres using a 4 inch pipe. With dual fuel use the engine operates with only 1 litre of diesel translating into a huge saving. This margin leaves enough room for farmers to risk increased wear and tear from biogas even when it is not cleaned of its slightly corrosive constituents such as Hydrogen Sulphide. In instances where the tube well is close to the bio-digester and the household or when the digester is built close to where water needs to be pumped up, there is no need for storage or use of pipes to transport gas to long distances. The fixed dome bio-digesters promoted by the project are by design not able to maintain constant gas pressure which can vary with the amount of gas being produced. Unlike generators however, diesel Petter engines can operate on lower as well as varying gas pressure, and therefore there is no need for compression.

Photos clockwise: Petter engine, engine and fan belt assembly, engine drawing water

[18] Pakistan Domestic Biogas programme is funded by the Dutch Embassy in Pakistan and SNV provided technical assistance.

Biomass

Biomass can be used to generate heat, which has its applications in generating electricity in large power plants. Although currently not suitable for smallholder irrigation, it can be considered in the future as an alternative for solar to power thermal pumps. No information is available about the potential for this. Additionally, it involves burning carbon, which makes this energy source renewable but not "green".

Bio-diesel and Bio-ethanol

Bio-diesel and bio-ethanol are good alternatives for fossil fuels to power water pumps, however, the use of valuable land for fuel crops replacing local staple crops is a serious concern. This option has not been considered in this study.

Hybrid Systems

For hybrid RE pumping systems, integrated and separated systems can be distinguished.

Integrated systems combine two or more RE sources or combinations of renewable and conventional energy sources. Integrated examples of high-end products include the Grundfos SQ flex series, combining solar and wind power. Low-cost options are rare, with one of the few examples being the wind ropepump in Nicaragua, where farmers complained about lack of water during low-wind spells, after which the windpumps were equipped with a small petrol engine[19] and another example being the Sunflower solar thermal pump, which has the option of manual pumping in case of lack of sun.

Separated systems can be defined as RE options with a conventional energy option like a small engine pumpset stand-by in case solar or wind power is not available, which can be an alternative to a multi-day storage capacity. Although investment costs are higher, the system overcomes the risk of losing crops.

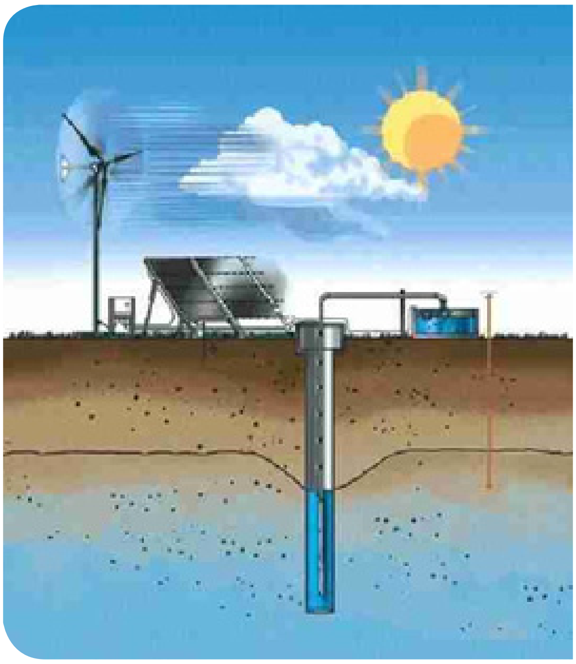

Figure 8 integrated hybrid pumping system (from: www.pumping.com.au)

While these technologies all have pros and cons, it is required to analyse the needs of a small-holder farmer before evaluating if these can improve livelihoods and how.

[19] The product evolved into the motor ropepump, which was preferred by the farmers.

Figure 9 smallholder farmer in Ethiopia

2.3 The Smallholder Farmer

In developing countries, smallholdings are usually farms supporting a single family with a mixture of cash crops and subsistence farming. The actual type of farming and plot sizes vary greatly from place to place.

Smallholder Irrigation

Again, irrigation practices and adoption rates vary immensely. Farmers that practice irrigation often do this only on a part of their total landholding and the size of the irrigated plot is generally limited by 1) the amount of water that can be lifted in a day, 2) how much a farmer is willing/able to invest in other inputs such as seedlings, fertilizer and pesticides, and 3) the labor available to work the land.

Mechanized Pumping versus Manual Pumping

Manual pumping options like treadle pumps or rope pumps are often mentioned as a first step into irrigated agriculture; at reasonable cost, the farmer can start irrigating and earn additional income. Once the farmer has the means, the step to mechanized pumping is made as farmers do not prefer the drudgery of manual pumping. With affordable Chinese engine pumpsets entering the market at comparable price levels with treadle and rope pumps, it is now seen that farmers skip the manual pumping step and start with mechanized pumping right away. In other places like the Nepalese Terai, the expansion of the electricity grid into rural areas in combination with the affordable electric pumpsets is also a reason to abandon manual pumping. RE options are considered to be an alternative for other power sources of mechanized pumping. For that reason, manual pumping has not been included in the comparison of technologies.

Water Use

The water requirement for crops varies over the growing season. If a farmer irrigates different crops that have been planted at different times, he can plan it in such a way as to maximize the capacity of the solar pumps. Tomatoes, for instance, require 6 l/m^2/day for only 25% of the growing season. The period before and after that they require only 1.5-3 l/m^2/day.

The plot size that can be irrigated, whether manually or mechanically, depends on the depth of the water. Roughly speaking, double the depth means half the plot size and vice versa. Generally SHI is limited to a maximum of 15m depth because beyond that, the economics are not necessarily favourable. Most SHI lifts no more than 7m of water.

Typical plot sizes for manual pumps are 400-1000m^2 with water at 10m depth and 1000-3000m^2 with water at less than 5m depth.

For small petrol pumps, the plot sizes can be up to 5000m^2 with water at 5m depth[20].

[20] Lessons learned in the development of smallholder private irrigation for high value crops in West Africa. S.Abric et al, 2011. World Bank joint discussion paper.

It would seem that solar pumps, capacity-wise, are positioned between man-operated pumps on the one hand (treadle pumps, rope and washer pumps) and small petrol pumps on the other hand. With a capacity of $6m^3$/day at 7m, the maximum plot under irrigation when based on maximum water requirements of 6 l/m^2/day[21] would be around $1000m^2$. However, if the planting is spaced out over the full range of a growing period (as for example the 5 months dry period in West Africa), the maximum water requirements of the plants are at different moments and the total area under irrigation can be doubled. Especially with high-cost pumps that have limited capacity like solar pumps, optimizing cropping patterns is essential to maximize the use of the pump. It would even be better to optimize the water use by using irrigation technologies like drip irrigation. However, due to the high costs and higher level of complexity, the use is limited to areas with serious water shortages.

Well Water versus Surface Water

Irrigation from surface water is generally advantageous as the water is available and the total lift of the water is low. In case surface water is not available, groundwater is accessed by a hand-dug well or borehole. However, a limiting factor for the use of water is the water depth as well as the capacity of the well.

As an option for pumping, solar pump options are submersible and fit into boreholes. Additionally, surface pumps can be found, but are less common. Price levels and performance are similar to that of submersible pumps, but surface pumps are less common in the current market of Chinese suppliers. For irrigation from surface water, the surface pump is often the preferred option.

Water Storage

Water storage for irrigation is not very common. In combination with wind pumps, storage is used to overcome dry spells. For drip systems, storage is needed to provide pressure to the drip lines 24 hours per day while pumping only a short time to fill the storage. In some known cases, storage is used in combination with a small petrol pump; farmers are unable to cope continuously with the large volumes of water produced by the petrol pumpset since water is applied to the plants manually by spray head. Therefore, storage enables the farmer to apply the water at lower flow rates.

Observing the range of technologies available and how they can be applied to the lifestyle and needs of small-holder farmers was the initial step in determining the best technological alternatives. Incorporating the financial dimension via an adapted calculation model helps to mitigate the observations made previously.

Figure 10 water storage for motor pumpset

[21] The actual water requirement depends also on the soil permeability, the type of crop, the actual evapotranspiration etc.

2.4 Financial Evaluation of Best Alternatives

The Calculation Model

To compare the RE options with the existing options for smallholder irrigation, a simplified calculation model was created and the summary is presented in table 1. Calculation sheets for each technology are presented in Annex 1.

This model factors in assumptions, related to the smallholder farmer as well as about the different technologies, which are based on data from technology producers and averages of figures such as fuel costs. The model is not intended for use for selection of the best technology for a given situation, but rather to demonstrate the influence of the key variables on the expected annual costs of the different technologies.

Key variables in the model

There are a number of key variables that influence the outcomes of the calculation model:

Fuel prices vary significantly throughout the world. The cost of fuel that can be saved determines the point where the initial higher investments for RE technologies are justified.

Interest rates have been included as smallholder farmers often do not have the means to make the large investments out of pocket. An estimated amount of **disposable cash** is included in the calculations, as it is seen in practice that smallholders do have the means to invest in, for example, low-cost petrol-powered pumpsets, but need loans for larger investments. For the purposes of this model, interest rates are taken for loans without collateral, for which pumps normally do not qualify.

Utilisation of the technology over the year relates to the number of crops per year or the length of the irrigation season, given in total months per year that the crop is under irrigation and assuming daily application of water. Costs of fuel-powered pumpsets are mostly related to usage, whereas the costs of RE options are related to ownership.

Plot size is based on assumptions about the average smallholder farmer and represents the plot size that is under irrigation. As the water output of RE technologies is limited (and for solar technologies the use is limited to 8 hours per day), it is not possible to increase the irrigated plot size without upgrading the technology. However, for the conventional technologies there is overcapacity, which means that the area of land under irrigation can easily be expanded.

Again, this is a simple model that explains trends and influence of the different variables in order to explore the limitations and opportunities of technologies, but variables should be adapted to specific context to get more accurate information.

Table 1 Calculation Model Overview

Overview sheet comparison technologies								
Conditions:								
Plot size	m^2	2 000						
Water depth	m	7						
Water requirement	m^3/days	6						
Irrigation months	months/yr	4						
Interest rate small loans	% /yr	25						
		petrol pump	**diesel pump**	**biogas combution engine**	**solar PV Low end**	**Solar PV High end**	**Solar Thermal Sunflower**	**Windmill**
Maximum plot size to be irrigated	m^2	72 000	288 000	6 000	2 800	2 800	3 467	5 000
Running costs								
Pump capacity	m^3/hr	9	36	9	1,2	1,2	1,3	1,5
Punning hours	hr/day	0,7	0,2	0,7	5,0	5,0	4,6	4,0
Running costs	€/day	0,48	0,12	0,00	0,00	0,00	0,00	0,00
Running costs per season	€/season	58,56	14,23	0,00	0,00	0,00	0,00	0,00
Annual costs								
Maintenance costs	€/yr	39	77	99	97	201	42,25	45
Financing costs								
Life time	yr	4	7	15	15	15	8	15
Total investment costs	€	170	440	950	530	2815	310	900
Of which paid cash	€	50	50	50	50	50	50	50
Cash depreciation	€/yr	13	7	3	3	3	6	3
Loan amount needed	€	120	390	900	480	2 765	260	850
Interest rate	%/yr	25%	25%	25%	25%	25%	25%	25%
Average yearly interest	€/yr	15	49	113	60	346	33	106
Yearly repaiment loan	€/yr	30	56	60	32	184	33	57
Total financing costs	€/yr	57,5	111,6	175,8	95,3	533,3	71,3	166,3
Total costs (operation and finance)	**€/yr**	**155,1**	**202,8**	**274,8**	**192,0**	**734,0**	**113,5**	**211,3**

Conclusions from the Calculation Model[22]

The break-even point for fossil fuel and RE

At present, fossil fuels are still an attractive alternative for RE, especially when the utilization of the equipment is short, for instance to bridge a short period with less rain or a dry spell. Also, as small petrol and diesel pumpsets are commonly used and services are widely available, this is a low-risk option for farmers.

Utilization, cost of use and cost of ownership

For the calculation model, an irrigation period of four months is used as a realistic period for comparison. One significant difference between fossil fuel and RE options is that the fossil fuel options have cheaper purchasing costs, but their annual costs are directly linked to the pump’s utilization, whereas RE, annual costs are mostly related to ownership of the technology. In practice, this means that RE technologies become more favourable the longer the irrigation season.

Furthermore, irrigation outside the main irrigation season can be done at no extra costs with RE options, which may be an incentive to increase production in the off-season. This effect is not taken into account in the table and could be part of a pilot study.

Financing costs

As the investment in the water pumping system increases, the smallholder farmer must finance the system through a loan, which can be achieved through either a formal or informal credit system. In the model, the interest rate of 25% is based on realistic values for credit through the formal system of loans for production means. Particularly for high-end products, financing costs make up a large part of the annual cost to operate the system and the comparative value of total operating costs per year depend very much on the actual interest rates. If financing of irrigation equipment needs to be done informally, interest rates can be as high as 10% per month (120% annually), which highly impacts the financial feasibility of RE options.

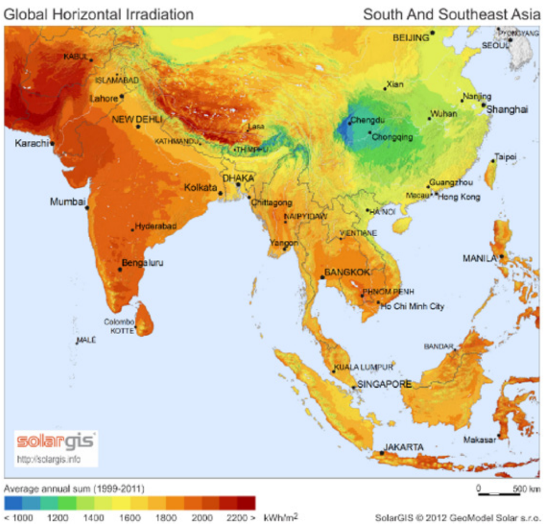

Figure 11 Solar potential mapping South East Asia (SolarGIS)

Geographical Location

A limitation of the model is that no considerations about the potential for wind and solar for specific locations is included; this potential needs to be evaluated on a case-by-case basis, for which a range of mapping software programs is available. First estimates can be done based on detailed maps that can be easily found on the web[23]. Other considerations like fuel costs and import duties on technologies can be included in the calculation model.

[22] Conclusions from the model are based on average values for the critical variables, which gives a good overview of the general picture and the directions. For a specific locality, price settings and other variables like interest rate and utilization rate can be very different and as a result, the conclusions may differ as well. It is recommended that for specific countries, the calculation model is updated and conclusions related to cost-effectiveness for RE technologies arejudged based on the local situation.

[23] See as examples www.solargis.info and www.3tier.com

2.5 Markets & Business

Nearly all recent irrigation projects with pumps powered by RE were either pilots that were donor-funded or large schemes that were heavily subsidized by the government.

In South-Asia, RE is very popular with governments because it is seen as a means to become less dependent on oil, as insolar power as oil substitution. In order to achieve this, there are large subsidies on solar PV for large-scale surface irrigation, particularly in India and Pakistan.

The market for PV solar power is well established in many less-developed countries, but not in combination with irrigation. Many shops sell solar panels, converters and pumps though specialized products, such as high quality solar systems, windmills, wind turbines and hydrams, are more difficult to find in most countries. However, aid organizations have created an alternative market for these goods in some countries, usually constructed in local workshops where people were trained for projects in the past. In countries like the Philippines, Nicaragua, Nepal, Burkina Faso, Kenya and Ethiopia, different kinds of appropriate technologies were successfully introduced, such as hydrams, ropepumps, biogas collectors, improved cookstoves and windmills, and are currently produced without the help of the initiators.

To evaluate the options for market development for irrigation with RE, the focus will be on **solar PV** and **solar thermal**, which are the technologies that shows the highest potential for use in SHI.

Market Trends

There is a clearly visible trend that shows the prices of solar panels for **PV pumping systems** decreasing in the coming years, mainly due to reductions in production costs as a result of increasing production volumes. Especially for PV pumping systems, the panels make up a major part of the investment costs, though installing more panels means that more water can be pumped.

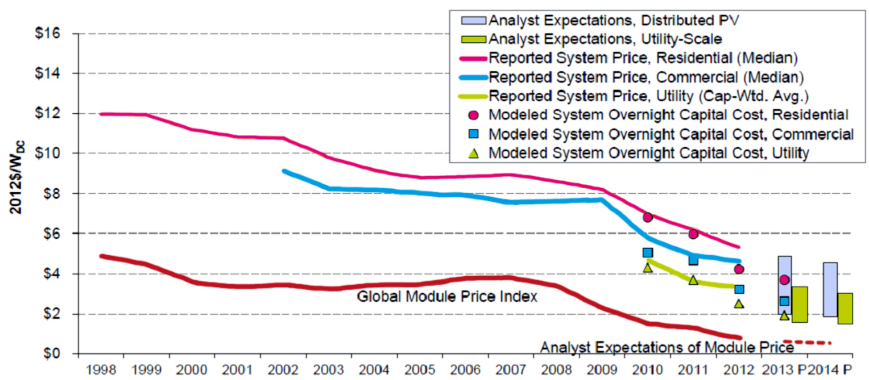

Figure 12
Reported, Bottom-Up, and Analyst-Projected Average U.S. PV System Prices over Time (Photovoltaic System Pricing Trends:Historical, Recent, and Near-Term Projections 2013 Edition; David Feldman e.a.

Also, recently a range of different PV solar pumping systems and components has become available from Chinese producers, making such systems affordable for a wider public. In addition, the decreasing PV panel prices should spark the development of pumping systems with higher capacity.

At the same time, **fossil fuel prices** continue to rise, which will speed up the process of financial viability of irrigation by other means than traditional fuel-based options.

Successful Experiences of Market Development of Solar Pumps

The only reported successful introduction of solar pumping for small scale irrigation is the **Benin SELF project**[24]. However, this has been a fully donor-driven undertaking and concerns relatively high capacity systems managed by a group of farmers serving small plots of individual farmers. Beyond this project, there have only been pilots -usually involving high-end solar pumps- initiated by NGO's or governments and that are of little relevance to SHI.

Conditions for Market Development

Marketing of RE products has a strong social marketing component in developed countries, where claims are made to promote the environmental responsibility of the intended user. In order to introduce new technologies commercially, however, the financial picture should appear favourable within the context. In some cases where financial capacity is very limited, such as in cases where smallholder farmers rely on production means like irrigation equipment for their existence, there are not enough means to experiment with new technologies. Furthermore, adaption rates to new technologies without track records are often low. To counter such challenges, market development should be done simultaneously from both the supplier and customer sides, creating demand on one hand, and on the other hand, making the product available once the demand emerges.

Conditions that need to be met are:

For the **end user** (farmer),[25] these conditions include:

- Affordable pricing and access to acceptable loans;
- Proven and reliable technology to avoid the risk of losing crops;
- Clear advantages over the existing alternative in terms of costs and ease of use ;
- High availability of the product, spare parts, and services (like trained mechanics).

For the **supplier**, the conditions include:

- Presence of a market for the products or the potential to easily develop this market;
- Potential to shift from a donor-based market (where NGO's are the main customers or individuals rely on subsidies for sales) to a non-subsidized market to avoid collapsing of the supply chain when subsidies are no longer available;
- Concentrated markets of sufficient scale to justify investments in stocking spare parts and training mechanics to provide after-sales services;
- Supportive measures or policies from national governments, including appropriate import duties.

[24] Noumon, T. C. A. Bienvenu (2008); Irrigation Schemes Using Solar Energy: A Case Study in Togblo, District of Athieme - Province of Mono - Benin.

[25] Focus is on smallholders as owners of the technology. Leases could be favourable to reduce the risk for the farmer. Other schemes, like the concept of Water Entrepreneurs is of less relevance, as the basis for this concept is the transportability of a technology, which is not the case for solar or wind-powered pumping. Also, the Water Entrepreneur needs to service multiple farmers, which assumes over-capacity of the pump. This is normally the case with diesel and petrol engine pumpsets, but not with RE options.

Actions to **meet those conditions** include:

- Market development including promotion and marketing campaigns to create sufficient demand;
- Development of efficient distribution models and business models;
- Private sector support, including setting up spare part supply and after-sales services to support early adopter farmers;
- Work on finance options for smallholder farmers to be able to purchase the more expensive RE technologies against good financial conditions;
- Technology comparative testing to be able to promote the best suitable technologies;
- Cooperation with national governments to eliminate or minimize import duties;
- Cooperation with national and local governments and NGO's to promote RE for SHI.

Though a certain number of limitations have been observed, it appears that a few constraints and risks of another type exist, which will now be listed.

2.6 Risks & Constraints

Several reasons can be pointed out as to why RE is not yet used on a large scale for SHI, the main reason being poor financial viability when compared to traditional petrol and diesel pumpsets. With dropping prices of PV panels, market introduction of low-cost (Chinese PV and Thermal) solar pumps and continued rise of fuel prices, this barrier is expected to disappear in the near future.

Risks and constraints that remain include:

Market and supply chain barriers need to be overcome; as with all new products on the market, solid supply chains and service networks need to be established to guarantee continuous operations. The availability of spare parts and skilled technicians is essential for this market considering that only a few days of downtime of the system can cause a full crop fail.

Financing needs greatly constrain the market. While small petrol pumpsets are relatively affordable, solar PV pumping systems, for example, are likely to exceed the price levels that farmers can afford without credit. Without favourable credit schemes in place, these technologies are out of reach for the farmers who would greatly benefit from their use. As loans required are quite high for SHI, financial risks have to be seriously analysed in access to credit mechanisms.

Lack of awareness is an obvious risk that can be overcome by marketing and promotion of the products to the point where a critical mass is reached.

National policies and taxation issues are a potential risk; in many (developing) countries there are low import tax regimes for agricultural equipment and RE-powered pumps should be considered as such.

Importation issues other than the usual hassle at customs when importing items is not expected, as the markets in developing countries are already flooded with Chinese consumer products. Also, the import channels to Africa through the warehouses in the Middle East appear to be well developed.

3. Conclusions and Recommendations

The most relevant conclusions drawn from the previous sections are summarized below. Recommendations are based on the current state of development of renewable SHI technologies as well as the vision of the authors as portrayed in the telephone interviews and from the strategic standpoint of their organizations.

3.1 Conclusions

Conclusions are given according to the following themes:

Knowledge: Lack of reported experiences and reliable data

Against expectations, the documented knowledge and experiences with RE options for smallholder irrigation in developing countries are very limited. When available, the projects are donor-funded and do not give realistic data about the long-term financial viability of irrigation with RE.

Technology: Affordable solar irrigation technologies are slowly becoming available

Low-cost complete PV solar pumping sets are becoming available on the market, with specific experiences in Africa. The use, however, is still experimental and the availability of field performance data is limited. Information about the lifespan of the technology or components is not at all available.

Economics: Financial modeling is key

With systems that require a loan to purchase, a good financing model with conditions that are favourable to the farmers is crucial. Even though annual operations costs of RE options are much lower, such schemes are necessary to make these systems financially competitive with the current fossil fuel-powered systems.

Opportunities: The tipping point

Evaluating the past initiatives for RE technologies for SHI and observing the technological developments and rising fuel prices, it seems that we are approaching the tipping point where RE is going to be economically more attractive than the fossil fuel alternatives. With this tipping point not far away, this is an excellent moment to engage in the promotion of RE solutions for smallholder irrigation.

3.2 Recommendations

Services to offer in promoting RE for irrigation

There are a number of barriers that impede the swift and large scale pick-up of irrigation using RE:

1. The technology is not yet fully developed
2. Buyers lack sufficient knowledge to make informed choices
3. The supply chain is not yet in place
4. Lack of financial products available for smallholder farmers

What is then required to move from the present experimental scale to large-scale implementation?

On a global level

The current situation with solar energy for SHI is analogous to that of handpumps for rural water supply back in the early 80's. At that time, the key actors agreed that handpumps would be the way forward for providing rural populations with drinking water, rather than the hitherto used diesel pumps. Decision makers were aware that much funding would be made available for rural water supply projects, but the weak link in the chain was the durability of the handpumps and the lack of knowledge as to which handpumps were suitable and which were not.

To address these issues, the World Bank took the initiative to launch a large-scale hand pump-testing programme, which covered a laboratory and a field test component. This exercise helped to weed out inferior products, stimulate manufacturers to improve their products and provided information to decision makers to make the right choice when selecting handpumps for their programmes. When the initial stage of testing was over, a knowledge centre was established called the Rural Water Supply Network (RWSN), which still exists today and has played an important role in the success of handpumps for rural water supply.

By benchmarking the success of applying handpumps for community water supply in the 1980's, the following components could be useful for the promotion of solar pumps for SHI:

- Lab testing of a range of solar pumps
- Field testing of the same pumps
- Establishment of a knowledge centre/clearinghouse

As there is currently no entity in the world at present where information on solar pumps for irrigation is systematically collected and made available to others, international organizations could lead this initiative and engage partners for specific input. Information can be made available to other organizations that can engage in this RE for smallholder irrigation network.

25

On a national level

Potential services on a national level are:

Private sector capacity-building to help building viable market structures needed for the sales and service of renewable irrigation options, which can include:

- Facilitation between foreign suppliers and local importers;
- Guiding local importers in creating a sustainable supply chain consisting of a local dealer network with outlets that stock pumps and spares as well as dispatch trained mechanics;
- Providing technical and business skill assistance at varying levels of the supply chain.

Promotion, awareness campaigns and (social) marketing of the products will help make the products known among smallholder farmers and reach a critical mass, after which commercialization of the products can continue without direct external support. Actions can include:

- Awareness campaigns and propaganda for irrigation empowered by RE through various means like road shows, advertisements in newspapers and on banners, interviews for radio and television, visibility in the field, etc.
- Demonstrations and trials of RE for irrigation at or near training centres, information or training on technical, agricultural and financial aspects (at farmer field schools, for instance).

Support of financial structures that are needed to finance the purchase of RE options, especially for the PV solar systems that require high initial investments. Actions can include:

- Partnerships with micro-finance institutions or local banks to develop specific financial products for financing RE irrigation equipment at favourable conditions;
- Creation of funds for guarantees that will reduce the risk for financial institutions to finance RE irrigation equipment;
- Development of leasing schemes for RE irrigation equipment that specifically serve smallholder farmers;
- Promotion of financial products through contacts working in the field directly with the farmers;
- Development of specific Village Level Credit and Savings schemes for investments in RE irrigation equipment.

Lobby work to enable favourable conditions for the use of RE sources or to remove barriers that counteract the use of the specific irrigation technologies. Options can include:

- Working with the national government on removing or reducing import duties on RE technologies for (smallholder) irrigation;
- Collaborating with national governments on streamlining import procedures for products (from China, for example);
- Working with regional and local governments in places where agricultural extension programs fall under their responsibility.

Working with implementing partners to get the technologies on the ground can be a good option. In many countries, there are active local NGO's that work on production and market chain projects with smallholder farmers. Beneficial actions can include:

- Identification and selection of (potential) implementing partners who have proven local expertise in smallholder irrigation, RE and microfinance and support those organizations with technical know-how;
- Implementation of a few pilot projects and development of a curriculum or training/information/extension programme, to be implemented by a local partner.

Potential strategic partnerships

Against the backdrop of promoting the use of RE for smallholder irrigation, strategic partnerships can include:

- Joint activities or programmes with not-for-profit companies or organisations that are already engaged in the technical side of RE for agriculture;
- Partnerships with technical universities;
- Joint activities or programmes with international and local microfinance institutions (MFI's) to make financing schemes available to smallholder farmers;
- Joint activities with local commercial banks to improve or develop products specifically aimed at investments in RE for SHI;
- Framework contracts with producers, (local)retailers or retailer networks and technical service providers regarding RE products.

In conclusion, this publication focused on different water pumping options that can be useful to smallholder farmers in developing countries. It highlights a lack of available data and technology, as well as difficulties in rendering the systems financially competitive compared with the current fossil-fuel powered systems, and a lack of financing schemes for wide commercialization. However, it indicates that the tipping point where RE-powered irrigation systems are more economically attractive than fossil-fuel alternatives is approaching, and can be reached more easily through additional effort in taxation, market and supply chain barriers, awareness-raising and financing needs.

4. Annexes

Annex 1: Prints of calculation sheets

Typical situation smallholder farmer

Plot size and water requirements		Unit	Remarks
Plot size	2 000	m^2	Plot size under irrigation
Total water lifting	7,0	m	Based on water depth and possible water lifting
Required pump capacity	6,0	m^3/day	Based on peak water need
Peak water need	6,0	mm/m^2/day	Based on maximum evaporation
Peak water need	6,0	l/m^2/day	
Average water need	3,0	l/m^2/day	Used in calculations

Operating costs variables			Based on:
			http://chartsbin.com/view/5437
Petrol / gazoline costs	1,20	€/l	http://chartsbin.com/view/1115
Dielsel costs	1,00	€/l	http://chartsbin.com/view/1128
Biogas costs	0,00	€/m^3	Cost of biogas unit not included

Financing costs variables			
Interest rates formal	15%	/ year	average rate for financing through official banks
Interest rates informal	25%	/ year	average rate for financing through micro finance without collateral
Disposable cash for investments	50	€ total	Money available that the farmer can invest without loans

Petrol pumpset

Technical specifications		Unit	Remarks
Capacity @ 7m total head	9	m^3/hr	
Maximum running hours per day	24	hr/day	
Maximum capacity per day	216	m^3/day	

Investment		Unit	Remarks
Investment of total unit	150	€	
Installation costs	20	€	Suction and pressure hoses
Lifetime, complete set	4	yr	

Operating costs		Unit	Remarks
Fuel consumption	0,6	l/hr	

Maintenance and repairs		Unit	Remarks
Yearly regular maintenance	10	€/yr	

Replacement of parts	Part value (€)	Every x years	cost	Unit
Spark plug	5	1	5	€/yr
Air filter	8	1	8	€/yr
Oil change	10	1	10	€/yr
Piston rings	12	2	6	€/yr
Total maintenance and repair costs			39	€/yr

Description
Typical 2-4 hp portable petrol engine pumpset with centrifugal pump.

Diesel pumpset

Technical specifications		Unit	Remarks
Capacity @ 7m total head	36	m^3/hr	Often limited by water source yield
Maximum running hours per day	24	hr/day	
Maximum capacity per day	864	m^3/day	

Investment		Unit	Remarks
Investment of total unit	400	€	Chinese or Indian brands
Installation costs	40	€	Hoses, checkvalves and clamps
Lifetime, complete set	7	yr	

Operating costs		Unit	Remarks
Fuel consumption	0,7	l/hr	

Maintenance and repairs		Unit	Remarks
Yearly regular maintenance	20	€/yr	

Replacement of parts	Part value (€)	Every x years	cost	Unit
Injector nozzle	12	1	12	€/yr
Piston rings	15	3	5	€/yr
Fuel pump element	20	1	20	€/yr
Oil change	15	1	15	€/yr
Fuel filter	5	1	5	€/yr
Total maintenance and repair costs			77	€/yr

Description
Typcally a 4-6hp diesel engine with centrifugal pump directly coupled or coupled with belt drive.

Solar PV low cost (Chinese) option

Technical specifications		Unit	Remarks
Capacity @ 7m total head	1,2	m^3/hr	See Tanzania test report
Maximum running hours per day	7	hr/day	
Maximum capacity per day	8,4	m^3/day	

Investment		Unit	Remarks
Investment of total unit	500	€	
Installation costs	30	€	Panel holder, hoses, clamps, mechanic
Lifetime, complete set	15	yr	

Operating costs		Unit	Remarks
Fuel consumption	0	l/hr	

Maintenance and repairs		Unit	Remarks
Yearly regular maintenance	10	€/yr	

Replacement of parts	Part value (€)	Every x years	cost	Unit
Controller	80	4	20	€/yr
Pump unit	200	3	67	€/yr
x		1	0	€/yr
Total maintenance and repair costs			97	€/yr

Description
Specifications and prices are based on a range of solar submersible pumps as supplied by different Chinese manufacturers. No field data is available about the durability of these products.

References
www.solartech.cn

Solar PV high quality (European) option

Technical specifications		Unit	Remarks
Capacity @ 7m total head	1,2	m^3/hr	Grundfoss SQF1.2-2
Maximum running hours per day	7	hr/day	
Maximum capacity per day	8,4	m^3/day	

Investment		Unit	Remarks
Investment of total unit	2800	€	
Installation costs	15	€	
Lifetime, complete set	15	yr	

Operating costs		Unit	Remarks
Fuel consumption	0	l/hr	

Maintenance and repairs		Unit	Remarks
Yearly regular maintenance	10	€/yr	

Replacement of parts	Part value (€)	Every x years	cost	Unit
Controller	500	7	71	€/yr
Pump unit	800	7	114	€/yr
Hoses and clamps	10	2	5	€/yr
Total maintenance and repair costs			201	€/yr

Description
Specifications and prices based on the European high-end submersible solar pumps from respected brands like Grundfos and Lorentz.

References
www.grundfos.com
www.lorentz.de

Solar Thermal

Technical specifications		Unit	Remarks
Capacity @ 7m total head	1,3	m^3/hr	
Maximum running hours per day	8	hr/day	
Maximum capacity per day	10,4	m^3/day	

Investment		Unit	Remarks
Investment of total unit	270	€	
Installation costs	40	€	
Lifetime, complete set	8	yr	

Operating costs		Unit	Remarks
Fuel consumption	0	l/hr	

Maintenance and repairs		Unit	Remarks
Yearly regular maintenance	20	€/yr	

Replacement of parts	Part value (€)	Every x years	cost	Unit
Diaphragm	5	1	5	€/yr
Pumpseal	1	1	1	€/yr
Bearings	25	4	6	€/yr
Small engine parts	20	2	10	
Total maintenance and repair costs			42,25	€/yr

Description
Specifications and prices are based on the Sunflower thermal solar pump as currently being marketed by Futurepump in Kenya. NB: market introduction of thermal solar pumps is only starting.

References
www.futurepump.com

Windmill (low cost, mechanical drive)

Technical specifications		Unit	Remarks
Capacity @ 7m total head	1,5	m^3/hr	Windropepump at 5m/s windspeed
Maximum running hours per day	10	hr/day	Varies between 0 and 24.
Maximum capacity per day	15	m^3/day	

Investment		Unit	Remarks
Investment of total unit	800	€	
Installation costs	100	€	
Lifetime, complete set	15	yr	

Operating costs		Unit	Remarks
Fuel consumption	0	l/hr	

Maintenance and repairs		Unit	Remarks
Yearly regular maintenance	20	€/yr	

Replacement of parts	Part value (€)	Every x years	cost	Unit
Ropes	10	1	10	€/yr
Washers	10	1	10	€/yr
Wooden bearings	20	4	5	€/yr
Total maintenance and repair costs			45	€/yr

Description
The wind rope pump is not used widely, but it is found to be the only option suitable for smallholder irrigation.

Annex 2: List of relevant background documents that were consulted

Consulted documents not used as reference in the main text:

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